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*Electron Beam Treatment for Removal of Trichloroethylene and Tetrachloroethylene from Streams and Sludge**

Florida International University and the University of Miami

Technology Description: Irradiation of aqueous solutions with high-energy electrons results in the formation of the aqueous electron, e^-_{aq}, hydrogen radical, $H^\cdot$, and the hydroxyl radical, $OH^\cdot$. These reactive transient species initiate chemical reactions capable of destroying organic compounds in aqueous solution, in most cases, oxidizing them to carbon dioxide, water, and salt. No sludge is formed and no pretreatment is necessary. The reaction by-products are non-toxic and thus this process represents a new technology for the restoration of contaminated water, soils, and sediments.

At one end of the system, an aqueous solution containing the hazardous organic chemical(s) is directed over a weir where it falls in a thin sheet (approximately 4 millimeters thick). At the other end of the system, a 1.5-million volt insulated core transformer (ICT) electron accelerator generates electrons and accelerates them to about 97% the speed of light. These accelerated electrons are propelled in a concentrated beam down a high-vacuum tube toward a scanner that scans the beam to a rectangular shape and directs it toward the aqueous solution that is flowing over the weir. It is at this point, when the electrons penetrate the waste stream, that treatment occurs. Studies were conducted at 120 gal/min and can be easily scaled up for larger applications (Figure 1). The process is essentially pH independent in the range 3-11.

Waste Applicability: This process can treat complex mixtures of hazardous chemicals in drinking water, groundwater, wastewater, and water containing up to 5% suspended solids. It can be used to remove various organic chemicals including chloroform, bromodichloromethane, dibromochloromethane, bromoform, carbon tetrachloride, TCE, PCE, *trans*-1,2-dichloroethene, *cis*-1,2-dichloroethene, 1,1-dichloroethene, 1,2-dichloroethane, hexachloroethane, 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, hexachloro-1,3-butadiene, methylene chloride, benzene, toluene, chlorobenzene, ethylbenzene, 1,2-dichloroben-

*This is the first in a series of bulletins that will report results of research conducted through this cooperative agreement.

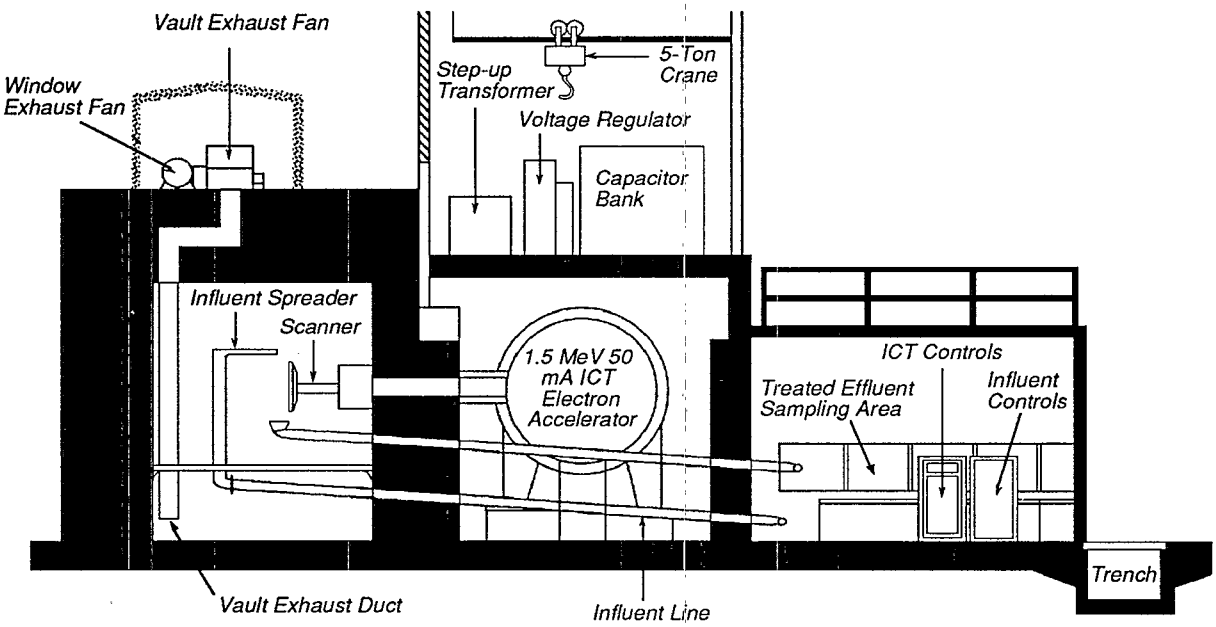

Figure 1. *Elevation of the Electron Beam Research Facility, Miami, FL.*

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zene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, *m*-xylene, *o*-xylene, dieldrin, and phenol.

Test Results: Several different experiments with electron beam irradiation of aqueous streams were conducted. These experiments had as their focus the effect of water quality, solute concentration, and irradiation dose on removal efficiency for TCE and PCE. To develop a more quantitative understanding of the factors that affect the removal efficiency of TCE and PCE from water by electron beam, experiments were designed that included the variables identified as important in the preliminary studies, i.e., total carbonate alkalinity, bicarbonate/carbonate ion speciation, solute concentration, and the presence and absence of clay. The waters used for the detailed experiments were potable water and raw and secondary wastewaters. Potable water is delivered to the plant with a pH of approximately 9 and an alkalinity of 45 to 60 mg L^{-1} as $CaCO_3$. For these conditions the bicarbonate/carbonate ion speciation is 7.41×10^{-4} M / 4.77×10^{-5} M, respectively. By lowering the pH of the water, using concentrated HCl, to pH 7, the speciation is altered to 6.98×10^{-4} M / 4.93×10^{-7} M. Add itional HCl lowered the pH to 5 and essentially eliminated the carbonate alkalinity.

To examine the effect of the addition of solids, kaolinite was added to give a concentration of 3% solids by weight. The addition of kaolinite resulted in a lowering of pH of the solution to approximately 7, and therefore only pH 7 and pH 5 could be directly compared for the removal of TCE and PCE in the presence and absence of clay.

In tests to compare the dose required to remove 99% of the TCE and PCE in three different quality waters at the lower and higher initial solute concentration, it was apparent that the removal of the TCE and PCE required a smaller dose in potable water than in either wastewaters. Although the quality of the three waters was quite different, there was not a large difference (< two-fold) in the removal efficiency between the three waters. The removal of PCE required a higher dose than TCE under equivalent conditions. This is consistent with the $OH^{\cdot}$ reaction rate constants of the two compounds.

More detailed studies were conducted at various TCE and PCE concentrations. The presence of suspended solids up to 3% had no significant effect on the removal of TCE or PCE when compared to solutions that had no clay. Solute concentration did not affect removal efficiency at the two lower concentrations studied. However, higher doses were required to achieve the same removal efficiency when the initial solute concentration approached 10 mg L^{-1}.

Reaction by-products were determined for tests containing the highest concentrations of TCE and PCE. Aldehydes were found but were at concentrations that accounted for less than 1% of the total carbon. Formic acid accounted for up to 10% of the carbon in the TCE and PCE at low doses, but at the higher doses the percentage conversion resulted in no more than 5% of the initial solute carbon. The formation of chloroacetic acids in irradiated solutions of TCE was not observed. Chloride ion mass balances showed a complete conversion of organic chlorine to chloride ion.

A paper detailing the results is available and has been submitted for publication.

For Further Information:

EPA Project Manager
Franklin Alvarez
Risk Reduction Engineering Laboratory
USEPA
26 West Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7631

Technology Developer Contact:

William J. Cooper
Drinking Water Research Center
VH 326
Florida International University
Miami, FL 33199
(305) 348-3049 FAX (305) 348-3894

Charles N. Kurucz
Departments of Management Science and Industrial Engineering
University of Miami
Coral Gables, FL 33134
(305) 284-6595 FAX (305) 284-2321

Thomas D. Waite
High Voltage Environmental Applications, Inc.
Miami, FL 33124
(305) 253-9143

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

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